January 2009

An ontology-based collaborative knowledge management network to enhance the reusability of inter-organizational knowledge

Nelson K. Y. Leung
University of Wollongong, knl164@uow.edu.au

Sim Kim Lau
University of Wollongong, simlau@uow.edu.au

Joshua Fan
University of Wollongong, joshua@uow.edu.au

An ontology-based collaborative knowledge management network to enhance the reusability of inter-organizational knowledge

An Ontology-based Collaborative Knowledge Management Network to Enhance the Reusability of Inter-organizational Knowledge

Nelson K. Y. Leung
RMIT International University Vietnam
VIETNAM
Nelson.Leung@rmit.edu.vn

Sim Kim Lau
University of Wollongong
AUSTRALIA
Simlau@uow.edu.au

Joshua Fan
University of Wollongong
AUSTRALIA
Joshua@uow.edu.au

ABSTRACT

A number of knowledge management (KM) approaches based on individual organizational KM strategies and business requirements have been developed without taking system interoperation into consideration. In this paper, a collaborative inter-organizational KM network is proposed to allow various organizations to access and retrieve inter-organizational knowledge. Ontology and mediation methods are applied to the network to enable heterogeneous knowledge management systems to communicate and collaborate with one another. The retrieved inter-organizational knowledge is used to support organizational KM process. While knowledge engineers can reuse the inter-organizational knowledge to create and evaluate its own organizational knowledge, general users benefit from the effectiveness and efficiency of searching for relevant inter-organizational knowledge within the network.

INTRODUCTION

In the past two decades, much effort has been spent on integrating heterogeneous information systems. This integration of information systems is essential to allow systems of different characteristics to communicate cooperate, exchange, and to reuse knowledge and services with one another. In the current Internet era, a transaction cannot be completed without accessing data, information, knowledge and services from third party website or information system. For instance, when a customer shops in an online store, the customer may wish to seek comments on the product quality from an external forum website. When the product is purchase, the online store will need to contact a financial institution for payment verification and confirmation. Then a delivery service provider is contacted to handle the delivery or shipment. In this example, a simple transaction involves interoperation and coordination of three heterogeneous information systems. This complexity will increase many fold in real-life practical transactional operations.

The concept of ontology is first applied by artificial intelligence researchers in intelligence system development to share and reuse knowledge. Ontology as a branch of philosophy dealing with the science of what is, the kinds and structures of objects, properties, events, processes and relations in every aspect of reality (Smith, 2003). It is further elaborated as a system of categories which accounts for a certain vision of the world (Guarino, 1998). The term, ontology, is later adopted by artificial intelligence community and Tom Gruber's definition, "ontology is an explicit specification of a conceptualization", has been widely accepted within the community (Gruber, 1993), in which a conceptualization is an abstract, simplified view of the world that we wish to represent for some purpose. Borst (1997) refines Gruber's definition by labelling ontology as a formal specification of a shared conceptualization. Based on Gruber's and Borst's definitions, Studer, Benjamins and Fensel (1998) make the following two conclusions: 1) an ontology is a machine-readable specification of a conceptualization in which the type of concepts used and the constraints on their use are explicitly defined, and 2) an ontology should only capture consensual knowledge accepted by large group of people rather than some individual. By representing knowledge with representational vocabulary in terms of objects and their interrelated describable relationships, inference engine and other intelligent programs will be able to understand the semantic of knowledge in the knowledge base.

Recent growth in the Semantic Web further amplifies importance of ontology. The Semantic Web is extension of the current Web, in which web content is represented in a structural form within ontologies by a finite list of vocabularies and their relationships (Berners-Lee et al., 2001). The role of ontology is to enable computer program, software agent and search engine to understand the semantics of web documents, thus making it possible for them to process the web content. Ontology also provides shared understanding of a domain to overcome differences in terminology from various sources (Antoniou & Harmelen, 2004).

It is impractical to expect each individual and organization to agree on using one or a small set of ontologies (de Bruijn et al., 2006). The adoption of such an approach is difficult. On one hand, it is a non-trivial task to define and maintain a large globally-shared and agreed ontology. On the other hand, this globally-shared ontology may hinder a system from reflecting its actual business requirements due to the constraints imposed in the ontologies such as the terminologies and relationships (Leung et al., 2007). Other researchers, such as Berners-Lee, Hendler and Lassila (2001), state that a large number of small domain-specific ontologies developed by communities, organizations, departments or even individuals are the likely scenario. While multiple ontologies will allow the system to be designed according to its actual requirements without committing to a particular set of common terminologies, data heterogeneity caused by such multiple ontologies can hinder the interoperation of such systems working effectively. Moreover inconsistencies of vocabularies and their relationships commonly described as ontology mismatch could happen. In this case, the ontologies need to be reconciled in some form to resolve the inconsistency issues.

This aim of this paper is to present a mechanism to reconcile mismatches between heterogeneous ontologies. We propose three meditation approaches to reconcile mismatches between heterogeneous ontologies from the aspect of Knowledge Management (KM). The rest of the paper is organized as follows. Section 2 describes various approaches of ontology mediation. Section 3 discusses the application of ontology and the mediation methods in KM. This includes the development of a proposed mediation selection framework and ontology-based collaborative KM network. Finally, section 4 concludes the paper.

APPROACHES OF ONTOLOGY MEDIATION

Individuals and organizations are developing their own ontologies based on individual requirements using different languages, scopes, coverage, granularities, modelling styles, terminologies, concepts and encodings. To reuse other ontologies, ontology mediation is required to reconcile mismatches between heterogeneous ontologies so that knowledge sharing and reuse among multiple data sources can be achieved (Predoiu et al., 2006). There are three major kinds of ontology mediations: mapping, merging and integration. Ontology mapping is a process of relating similar concepts and relations from different ontologies to each other in which the correspondences between different entities of the two ontologies are formulated as axioms in specific mapping language (de Bruijn et al., 2006). This process does not require any adaptation; ontology mapping specifies just a part of the overlap between ontologies which is relevant for the mapping application (Scharffe et al., 2006). Two common approaches used to establish mapping between ontologies are:

- Using a common top-level ontology so that different ontologies are mapped together indirectly by a top-level ontology (Scharffe et al., 2006). This way, conflicts and ambiguities can be resolved because the concepts used in the ontologies are inherited from this common top-level ontology. However, this approach has three major drawbacks. First, constructing a large-scale common top-level ontology from scratch is never a simple task. Even if we take a simpler path of merging different local ontologies together, the experience of building the Suggested Upper Merged Ontology (SUMO) show that the actual merging processes are much trickier, not only because there is inconsistency between chunks of theoretical content but also due to structural differences between local ontologies (Niles & Pease, 2001). Second, this approach can only be applied in a relatively stable environment where maintenance is minimal because a substantial amount of resources and overheads are required to maintain the common top-level ontology. Thirdly, the established mappings between local ontologies and top-level ontology can be affected easily by the elimination and addition of local ontologies as well as changes in either local or common ontologies. This is because local ontologies are related indirectly with each other through the common top-level ontology.

- A one-to-one mapping approach to create mapping between each pair of ontologies (Predoiu et al., 2006). The lack of a common top-level ontology in this approach has the advantage of making it possible to be applied in a highly dynamic environment. This advantage may be offset by the lack of common terminologies, thus increasing the complexity of defining mapping between local ontologies. However this approach is not practical when a large number of heterogeneous ontologies are involved, extra mappings and efforts are required to control and maintain the one-to-one mappings.

The second type of ontology mediation approach is merging. Unlike mapping that links two separate ontologies together in a consistent and coherent form, ontology merging creates a new ontology (in one subject) by unifying two or more different ontologies on that subject and it is usually difficult to identify regions of the source ontologies from the merged ontologies (Pinto

& Martins, 2001) While the ontology mapping approach keeps original ontologies unchanged, the merging approach requires at least one of the original ontologies to be adapted (Ding et al., 2002). While a majority of the Semantic Web researchers foresee the growth of adopting the approach of developing enormous amount of small domain specific ontologies, McGuinness et al (2000) argue that some industries and organizations still need to develop very large and standardized ontology, such as SNOMED CT which is a comprehensive clinical ontology developed by the College of American Pathologists that contains about 344,549 distinct concepts and 913,697 descriptions (Lussier & Li, 2004). It may be more efficient and effective to merge existing ontologies than to build a large ontology from scratch. In practice the process of ontology merging is more complicated because the ontologies have been developed by various people for different purposes with different assumptions using different vocabularies (Pinto & Martins, 2001).

A widely used process in ontology mapping and merging is ontology matching, which can be defined as the process of discovering similarities between two ontologies with the purpose of establishing semantic relationships between them (Studer et al., 1998). It determines the relationships exist between two sets of entities that belong to two distinct ontologies. In other words, it is the process of finding a corresponding entity in the second ontology for each entity (for example, concept, relation, attribute and so on) in the first ontology that has the same or the closest intended meaning. This can be achieved by analysing similarity of the entities using a metric (Ehrig & Sure, 2004). Ontology matching (or similarity computation) can be processed by exploiting a number of different techniques. To provide a common conceptual basis, researchers have identified different types of ontology matching techniques classifications. For example, Shvaiko and Euzenat (2005) propose a classification consisting of ten ontology matching techniques. Another example is the classification framework developed by Leung et al. (2008), which provides an effective method to identify seven types of matching techniques and its related executive approach by examining the input of mediation system. These seven types of techniques are string-based, linguistic resources, constraint-based, alignment reuse, graph-based, taxonomy-based and model-based.

Finally, the third type of ontology mediation is integration. Pinto and Martins (2001) define ontology integration as a process of building ontology in one subject by reusing one or more ontologies from different subjects. In this approach, it is always possible to identify regions of source ontologies from the integrated ontology. Here the source ontologies may need some form of refinements before they can be aggregated, combined and assembled to form the resultant ontology. It is also important to include ontology integration in the early stage of ontology building process, preferable during conceptualization and formalization, in order to simplify the overall ontology building procedure.

APPLICATION OF ONTOLOGY IN KNOWLEDGE MANAGEMENT

The concept of ontology and its related mediation methods can be applied to solve the interoperation problem in distributed KM environment. The purpose of KM is to preserve and capitalize on organizational knowledge for future benefit of organizations. KM encourages organizations to create and reuse knowledge continuously for the purpose of innovation and enhancement of product, service and operation. It also aims to improve quality, content, value and transferability of individual and group knowledge within an organization (Mentzas et al.,

2001). This is achieved by organizing formal, direct and systematic process to create, store, disseminate, use and evaluate organizational knowledge using appropriate means and technologies.

Nonaka et al. (2001) suggest four methods to create organizational knowledge based on interaction between explicit and tacit knowledge. Tacit knowledge is personal, complex and hard to communicate and formalize, on the other hand, explicit knowledge is structured, relatively simple and easily captured, recorded, documented, codified and shared (Goh, 2002). The first method is called socialization. It is the process of developing new tacit knowledge from tacit knowledge embedded in human or organization through experience sharing, observation and traditional apprenticeship. The second method known as externalization; it is a process of turning tacit knowledge into new explicit knowledge by transforming tacit knowledge in the form of document such as manual and report. The third method is combination. This is the process of merging and editing "explicit knowledge from multiple sources" into a new set of more comprehensive and systematic explicit knowledge. The last method is internalization; it is the process of embodying explicit knowledge as tacit knowledge by learning, absorbing and integrating explicit knowledge into individual's tacit knowledge base.

The second and third stages of KM, store and disseminate, are often linked with technologies. Explicit knowledge that has been created is collected and stored in some sort of database or knowledge base to enable users to access using "search and retrieve" tools, intranets, web applications and groupware (Alavi & Leidner, 1999). The retrieved knowledge can then be used by other knowledge workers to add value to current business process, implementation and coordination of organizational strategy, to predict trends, deliver new market values, to create new knowledge or to solve existing problems (Bailey & Clarke, 2001). The fifth stage of KM is knowledge evaluation, to eliminate incorrect or outdated knowledge (Alavi & Leidner, 1999). This way the organization creates new knowledge to replace any invalid or outdated knowledge.

However some of the KM approaches are not proficient in distributed knowledge environment (Leung & Lau, 2006). A number of the approaches are customised to suit different organizational KM strategies and business requirements without considering system interoperation issue. The lack of interoperability means that heterogeneous knowledge management systems (KMS) from different organizations are not able to communicate, cooperate, exchange and reuse knowledge with one another. Wagner and Buko (2005) argues that knowledge-sharing in an inter-organizational network promotes a richer and diversify body of knowledge compare to within an organization.

The non-collaborative also KMS have several disadvantages for both knowledge workers and knowledge engineers. In terms of knowledge workers, they have to spend a lot of time and effort to look for relevant knowledge from different KMS because they often require to access knowledge from other knowledge sources to complete their tasks. For instance, an investment manager has to retrieve various company financial reports, share performance reports and regional economy reports from external sources in investment portfolio planning. In terms of knowledge engineers, a lot of resources are spent in creating and updating organizational knowledge although the same knowledge is easily obtainable from other KMS. External source of knowledge is essential, therefore a new inter-organizational KM practice needs to be developed to enhance the interoperability among independent KMS and to encourage sharing of

knowledge across organizational boundaries (Oinas-Kukkonen, 2005).

Nevertheless, the absence of a common language or standardization has created a barrier for collaboration between different KMS (Sheth, 1999). Although the emergence of middleware technology has provided a way to enhance the interoperability of KMS, the concept of middleware is difficult to accommodate as each pair of the KMS are required to implement a tailor-made middleware for interoperation (Leung et al., 2007). Since a single KMS is linked to other systems via the Internet, it is impractical to customize and install a middleware for each connection. Another deficiency of middleware is the possibility of complete re-construction when minor modification does not produce the desired result.

Ontology-based Collaboration Inter-organizational Knowledge Management Network

Let us consider the following scenario. At the University A, if an academic researcher is in need of information systems (IS) related literatures (for instance, literatures related to "inter-organizational KM"), the first thing s/he can do is to access the website of the university library. S/he can then type in a set of keywords in the search interface of the library website to determine whether the relevant literatures are available in the library. If it does, then s/he can choose to pick up the literatures from the library or download them in soft-copy format. If not, s/he will have to search again in various literature knowledge bases subscribed by the library. Literature knowledge bases allow subscribers to retrieve literatures such as journals, conference papers, books or other forms of manuscripts. Unfortunately, this process needs to be repeated for every single knowledge base until s/he can find the desired literatures. Each knowledge base contains different sets and types of literatures based on publishers or disciplines areas such as IEEE Xplore (IEEE) and ACM Digital Library (ACM) mainly contain computer related journals and conference papers that are published by IEEE and ACM respectively whereas Australian Digital Theses Program stores thesis of any disciplines produced by postgraduate research students at Australian universities. Finally, if s/he still cannot find any related literature, s/he may choose to search again using other search mechanisms such as Yahoo and Google.

In this research, we propose to use ontology and its related mediation methods to solve the collaboration problem of heterogeneous KMSs in the Internet environment. Ontology is incorporated to allow explicit knowledge to be annotated in the form of machine processable metadata. Although different organizations possess their own set of ontologies, the mediation methods are capable of reconciling the underlying heterogeneities of ontologies. In this way, the concept of ontology and mediation enables organizational KMS to understand incoming request and the returned knowledge, thus making it possible for them to collaborate and communicate with each other. We argue that the knowledge reusability and mismatches reconcilability of ontology and its related mediation methods can further contribute towards reformation of existing KM frameworks that focus only on managing organizational knowledge. Therefore, we propose to develop an ontology-based collaborative inter-organizational KM network that provides a platform for organizations to access and reuse inter-organizational knowledge with a similar domain. Here, inter-organizational knowledge is defined as a set of explicit knowledge formalized and created by other organizations. In the network, the formalized inter-organizational knowledge is reusable in a way that it can be retrieved by any organizations to support their own KM processes in terms of knowledge creating, storing, dissemination, using and evaluation.

Each network should only contain knowledge of a specific domain to ensure knowledge workers can retrieve relevant knowledge in an efficient manner, for example, an IS network should only provide knowledge in the discipline area of IS. Once an organization recognizes the need for a certain type of knowledge, the organization can invite other organizations and knowledge providers with the same knowledge domain to establish a network together. For example, given that academic researchers in IS discipline have to access different knowledge bases in order to obtain the desired knowledge, the library at this university decides to invite other libraries and academic publishers to establish a knowledge network that contains only IS knowledge. When the network for a particular knowledge matures, organization in need may choose to join instead of establishing new one. Within a network, each organization or knowledge provider must commit to a mutual agreement to allow other participants to access an agreeable portion of ontology and the associated knowledge in its knowledge base. Besides, a single organization or knowledge provider can commit to more than one network of different domains. For instance, the library of the University A may choose to commit to networks of IS, economics, mechanical engineering, education and chemistry whereas IT help desk of Company A may choose to commit to network of other hardware and software providers' knowledge bases.

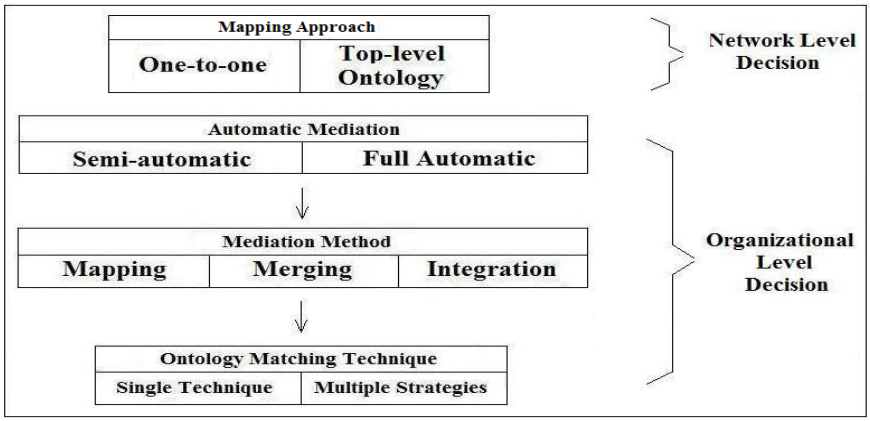
Selection Framework for Ontology Mediation

Before continuing the description of the proposed network, the participating organization must first make four important decisions related to ontology mediation. Figure 1 illustrates a selection framework for ontology mediation in the form of a matrix. The first decision is whether to adopt top-level ontology or one-to-one as the network level mapping approach. As this decision is on the network level rather than an organizational aspect, the organizations as a whole must compromise in order to select the most appropriate mapping approach for the benefit of the entire network. The decision process should include a thorough assessment and discussion from the aspects of resources, expertise and frequency of modification among all organizations in the network. The top-level ontology approach can only be applied to an environment where maintenance effort is minimal even though such an approach can provide a better mechanism to resolve conflicts and ambiguities. Whenever a minor modification is performed in one of the ontologies in the network, the shared ontology used in the top-level ontology approach may need a complete reconstruction. The organizations must also make sure that they have sufficient resources and expertise to build the shared ontology. If frequent maintenance is required or resources and expertise are insufficient, it may be more appropriate to use the one-to-one approach.

The second decision is whether to perform mediation automatically or semi-automatically. Mediation can be performed semi-automatically which requires the support of automatic tools as well as human intervention. The forms of support provided by automatic tools include similarity computation, post-mediation verification, validation, critiquation as well as conflict recognition and resolution. Although semi-automatic mediation could have a better performance than the manual one in terms of accuracy, it still substantially relies on human efforts and can be time consuming. Without human intervention, the process of semi-automatic mediation cannot be completed, thus compromising accuracy of the mediation result. As semi-automatic tool is not capable of supporting mediation on-the-fly, it would be ideal to perform mediation automatically. Unfortunately automatic tools are unable to detect and interpret concepts that do not have close correlation. Moreover, it may also fail to handle any unforeseeable situations as

the tool is designed to perform mediation under certain pre-defined conditions. However, if automatic mediation is adopted and inference mechanism is built on top of it, then inaccurate results can reduce the value of the mediation process.

Figure 1: Selection Matrix for Ontology Mediation.



The third decision is whether to adopt merging, mapping and/or integration as the desired mediation method for each organization. Each organization can choose one or more methods based on its own need. The concept of mapping enables ontology to be developed in response to its actual business requirement and is more suitable in a fluctuant business environment. Here, fluctuant business environment refers to an environment where organizations need to modify their ontologies in a frequent manner. Unless ontology has undergone major modification, simple modification, such as adding or deleting a concept from ontology, may merely require updating the mappings accordingly. Alternatively, merging is an appropriate method for creating an ontology that combines common views of multiple source ontologies. In other words, the merged ontology should include all possible correspondences and differences among the entire set of source ontologies. As a result, the merged ontology could act as 1) a single ontology used to substitute individual source ontology, 2) a shared ontology (reference point) used in top-level ontology mapping approach, or 3) an organizational ontology that includes all possible views of other organizations' ontologies. Unlike merging, integration selects only opposite modules from individual source ontologies to form an integrated ontology. Thus, integration is appropriate for organizations to customize ontologies based on their own needs. For example, the library at University A can customize a KM-based ontology by integrating portions of ontologies derived from other libraries and other academic publishers.-The final thing needs to be considered is whether to adopt single or multiple matching techniques. In the decision process, organization must also take into consideration execution duration, acceptable level of matching accuracy and resources level for implementation. In general multiple strategies are expected to generate more accurate result than single matching technique; however it is not always the case. The choice of aggregation algorithm and cut off point also plays an important role in determining the level of matching accuracy. When choosing multiple strategies as its matching technique, organization must conduct a series of experiments with the purpose of finding the right combination of multiple strategies, aggregation algorithm and cut off point to produce the most accurate result. Compare with single matching technique, multiple strategies are relatively difficult to design and implement and it requires longer execution time.

Operation of the Inter-organizational Knowledge Management Network

The reconcilability of ontology mediation allows the participating organizations to reuse inter-organizational knowledge within the network even if there are fundamental differences among organizations in terms of KMS structures and formats. Under mutual agreement, organizations are permitted to retrieve inter-organization knowledge and the retrieved knowledge can be reused to support the five stages of KM process. Conventionally, technology has very limited contribution in knowledge creating stage especially in socialization, externalization and internalization where tacit knowledge is involved. For example, word processing tools can be used to record and visualise explicit knowledge in externalization and internalization, whereas communication tools such as email and telephone provide platforms for exchanging explicit knowledge in socialization.

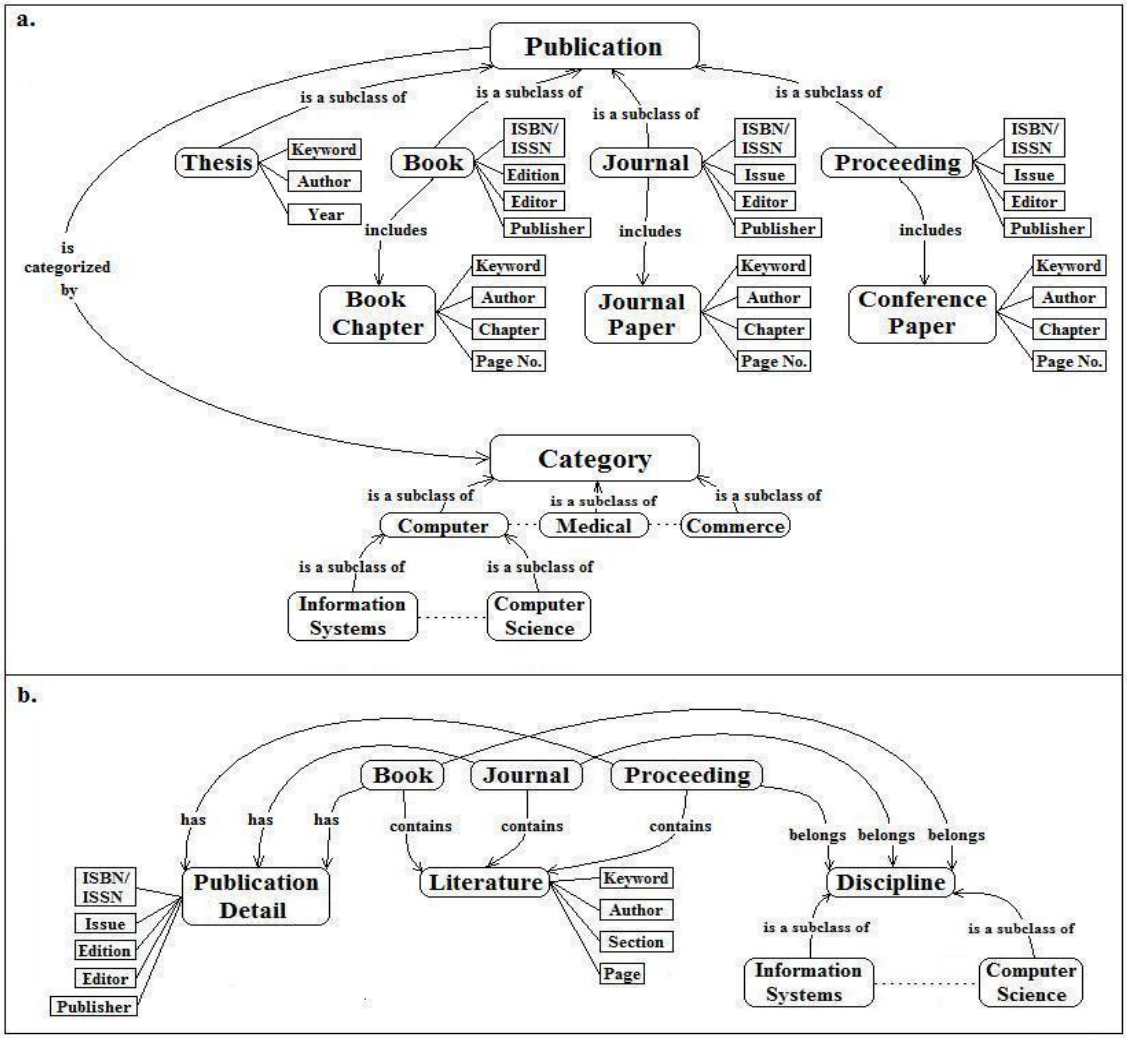
However, ontology merging tool can provide a practical way to create knowledge by combining two or more ontologies together semi- or automatically in the network. This can be achieved on both network and organizational level. On the former level, merging tool is capable of creating a shared ontology for top-level mapping approach that contains common views of all organizational ontologies in the network. On the latter level, organization can create its own domain specific ontology by merging relevant ontologies from other organizations within the network. In addition, ontology integration tool provides an alternative way to create knowledge. Using integration method, organization can create its own knowledge by integrating relevant parts of ontologies from other organizations in the network into its own ontology building process. As a result, both merging and integration tool enable organizations to reuse not only the contents of other ontologies but also their associated inter-organizational knowledge stored in the knowledge bases of other organizations. While ontology merging and integration are never a trivial task even with the assistance of automatic tools, they are still less demanding than building it from scratch.

Knowledge dissemination tool allows user to retrieve and use knowledge from organizational knowledge repository. If user cannot find suitable organization knowledge, s/he has to seek from other external sources. This can be achieved by creating mappings among ontologies of different organizations either semi- or automatically with the support of ontology mapping tool. The established mappings allow one KMS to access another KMS in the same network. Besides, it is also practical for mapping to be performed on-the-fly. In this case, automatic mapping tool is responsible to look for, select and establish mapping with the most relevant concepts and properties from other ontology in the network. Whenever the required knowledge is not available in the organizational repository, the KMS is able to retrieve and deliver inter-organizational knowledge in a “black box” through the establishment of mappings. In addition, inter-organizational knowledge can be reused to support knowledge evaluation process. This is accomplished by setting up dedicated mapping between two or more ontologies. Once a piece of inter-organizational knowledge is updated, this it will be translated into a suitable format and delivered from source knowledge base to the target automatically via the pre-established mappings. To demonstrate the reconcilability of ontology mediation and reusability of inter-organizational knowledge in the network, let us consider the following scenario.

Assuming University A realizes that there is an increasing demand for IS related knowledge, and this demand cannot be satisfied with current collection of publications in the library.

Consequently, University A decides to invite knowledge providers and libraries of other universities to establish a network that contains IS related literatures which include libraries of University B, University C, University D, Publisher ABC and Publisher XYZ. Except for University D, all other participating organizations possess ontologies. Figure 2a shows a partial view of the classification ontology adopted in the library of University A. In this ontology, the publication concept has concepts that include book, journal, proceeding and thesis as its subclasses and each subclass is described by a set of properties such as International Standard Book Number (ISBN), International Standard Serial Number (ISSN), and publisher. Concept category and its subclasses are used to distinguish publications into different subjects such as concept computer, medical, commerce, computer science and so on. Given that this network only supports IS related knowledge, therefore the library of University A is willing to share publication that belongs to concept computer and its subclass information systems. As publication may contain chapters written by different authors, the ontology reflects it by including concept book chapter, journal paper as well as conference paper and their related properties as an extension of concept book, journal and proceeding respectively. Figure 2b shows a partial view of the classification ontology in Publisher XYZ. There are three major concepts in this ontology, that is, concept book, journal and proceeding. Each concept has a set of publication details (such as issue and edition), contains a set of literatures and belongs to one discipline (such as information systems). The above three components are represented by concept publication detail, literature and discipline respectively. Similar to University A, Publisher XYZ also agrees to share literatures that are classified under concept information systems.

Figure 2: Partial View of the Classification Ontology Adopted in (a) Library of University A and (b) Publisher XYZ. Round Rectangular Nodes Represent Concepts. Rectangular Nodes and Labels on the Arcs Represent Properties.



After careful consideration, the six organizations have reached a mutual agreement not to adopt top-level ontology as the network-wide mapping approach. This decision is based on the fact that there will be many more organizations wishing to join the newly established network, so the shared ontology built for the top-level ontology mapping approach may require to undergo a series of reconstructions. Although they have sufficient expertise and resources to build and reconstruct the shared ontology, it is not cost effective to do so. In addition, the reconstruction works will definitely affect the stability and performance of network-wide mediation because the shared ontology will be mapped by all other ontologies as a reference point. At this moment, the organizations prefer to use one-to-one mapping approach. However they have agreed to review the mapping approach after the organizations wishing to join the network stabilized.

As the library of University D does not possess ontology, the library has to create one in order to fulfil the requirement of joining the network. Instead of building the ontology from scratch, the library decides to reuse ontologies from other organizations and integrate them into its own

development process using ontology integration method. However, the chosen ontologies must be similar to the library's actual classification in terms of publication and discipline in order to minimize the degree of modification. For example, the concept publication and its subclasses in the ontology of University A are more appropriate than those defined in Publisher XYZ as the subclass thesis; book, journal and proceeding defined in the ontology of University A are very similar to the actual classification used in the library of University D. Based on the criteria, the library reuses only a portion of the two ontologies that include the concept publication and its subclasses derived from the ontology of the University A as well as the concept discipline and its subclasses derived from the ontology of Publisher XYZ (see Figure 3). In the ontology development process, the library of University D can reuse not only the ontologies of other organizations; it also has the inter-organizational knowledge associated with the instance of the integrated ontology. As illustrated in Figure 3, the softcopy of the thesis described by the instance of the integrated ontology, thesis "Turning User into First Level Support in Help Desk: Development of a Web-based User Self-help KM System" in discipline IS, can be captured from the knowledge base of the University A and stored in the knowledge base of University D. This integrated ontology created by the library of the University D has resulted in additional function. By establishing dedicated mappings between the integrated ontology and its ontology providers (that is, the ontologies of University A and Publisher XYZ), the associated publication captured in the knowledge base of University D can be automatically updated as long as there is an revised version generated from the ontology providers. In this case, when the thesis "Turning User into First Level Support in Help Desk: Development of a Web-based User Self-help KM System" has undergone a minor revision in the knowledge evaluation process, the revised thesis will not only be stored in the knowledge base of University A, it will also be broadcasted to other KMS through the dedicated mappings that includes the knowledge base of University D. To allow general user to retrieve and use inter-organizational knowledge, organizations are required to establish mappings between its own ontology and ontologies of other organizations in this network. As shown in Figure 4, each broken line represents a mapping between a pair of concepts or properties that belong to two different ontologies. Making use of string-based and linguistic resources matching techniques, two similar concepts from the ontologies of University A and Publisher XYZ are mapped with each other. For instance, two identical concepts (such as journal) and two properties that are synonyms (such as section and chapter) from the ontologies of University A and Publisher XYZ are mapped together.

Figure 3: Process to Develop University D's Ontology Using Integration Method.

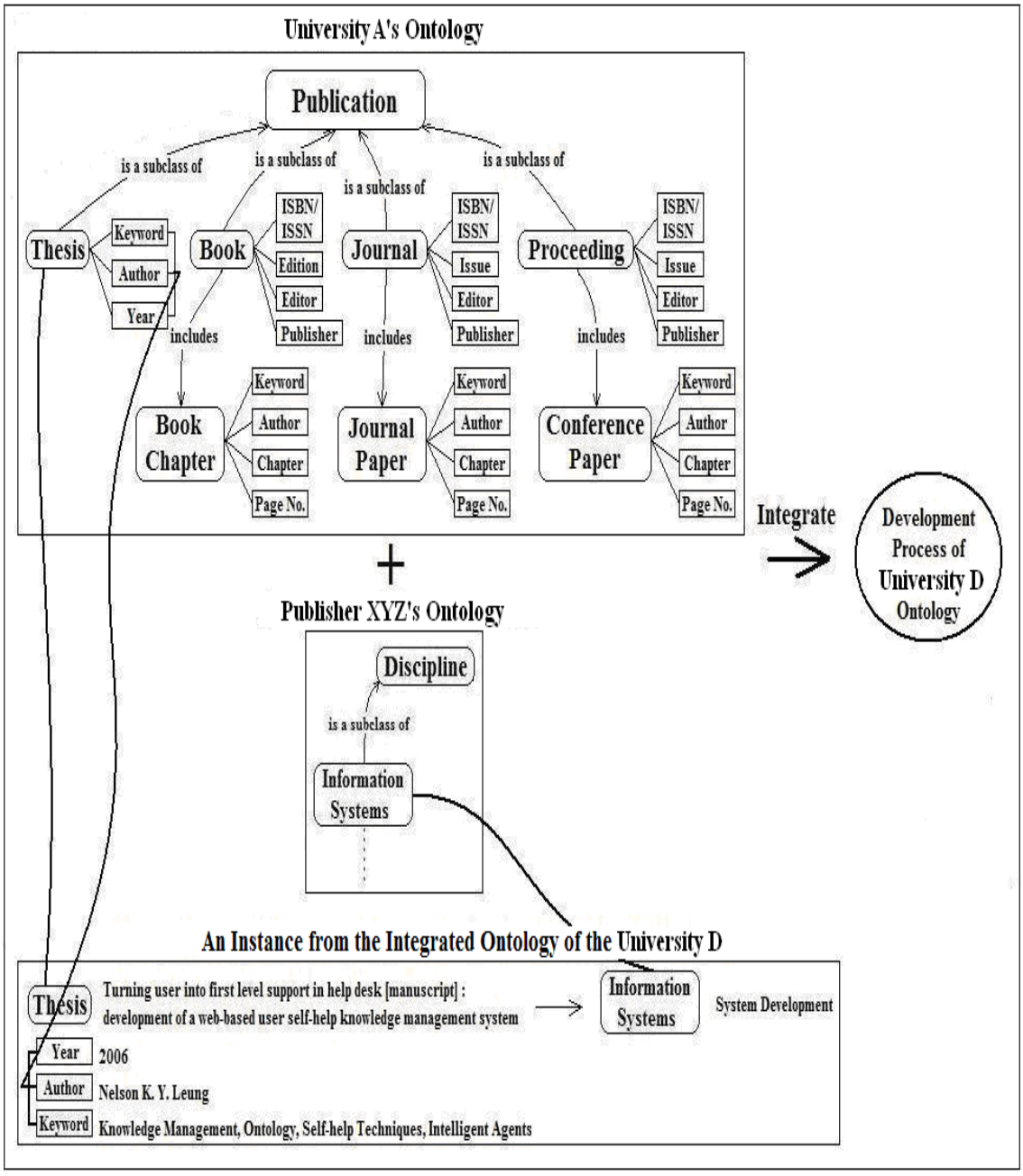
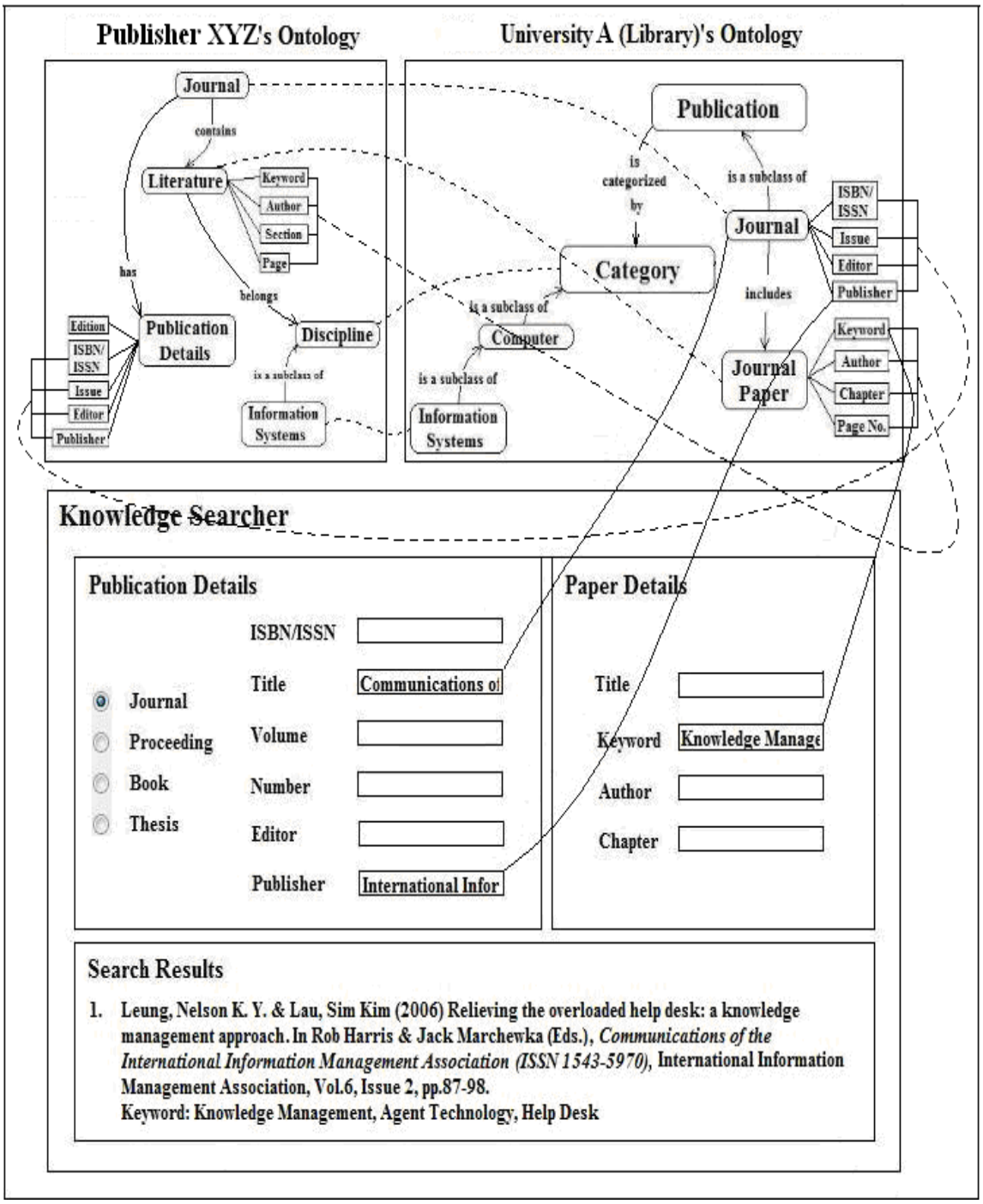


Figure 4: Inter-organizational Knowledge Retrieval and Reusing Process.



In Figure 4, a user is searching for suitable journal papers by filling in data on title, publisher and keyword fields on the "knowledge searcher" which is designed to be used as a search interface for the KMS at the library of University A. Since the KMS cannot provide journal that satisfies this query, the system begins to search other KMS including Publisher XYZ. The mappings allow the KMS of Publisher XYZ to understand the incoming query. For example, the details provided in the title, publisher and keyword fields on the search interface are similarly referring

to the concepts journal, property publisher and property keyword that belong to the ontology of Publisher XYZ. As long as the requested journal is available in the knowledge base of Publisher XYZ, it will be delivered to the search interface of University A. Subsequently, the journal will be displayed as if it is retrieved from its own knowledge base. In other words, the entire inter-organizational knowledge retrieval and displaying mechanism are performed in a "black box" manner.

CONCLUSION

The organizational-based KM approaches have resulted in collaboration problem in which organization is not capable of reusing inter-organizational knowledge even though the required knowledge is available in other organizations. An ontology-based collaborative inter-organizational KM network is proposed to solve this problem. To establish the network, a selection framework is proposed to assist organizations in choosing suitable ontology mediation approaches, ranging from mapping approaches, levels of automation, and mediation methods to matching techniques. The knowledge reusability and mismatches reconcilability of ontology and its related mediation methods enable organizational KMSs to understand incoming request and returned knowledge, thus making it possible for collaboration and communication. By annotating knowledge explicitly in the form of machine processable representation, organizations joining the network can access, retrieve and reuse domain specific inter-organizational knowledge to support the five stages of organizational KM process. While knowledge engineers could reuse inter-organizational knowledge to create and evaluate organizational knowledge, general users also benefit from the effectiveness and efficiency in searching for relevant inter-organizational knowledge within the network.

REFERENCES

Alavi, M. & Leidner, D. (1999). Knowledge Management Systems: Issues, Challenges, and Benefits. *Communications of the Association for Information Systems*, 1(7), 1-37.

Antoniou, G. & Harmelen, F. (2004). *A Semantic Web Primer*. MIT.

Bailey, C. & Clarke, M. (2001). Managing Knowledge for Personal and Organisational Benefit. *Journal of Knowledge Management*, 5(1), 58-67.

Berners-Lee, T., Hendler, J., & Lassila, O. (2001, May). The Semantic Web. Scientific American, May.

Borst, W. (1997). Construction of Engineering Ontologies for Knowledge Sharing and Reuse, Centre for Telematica and IT.

de Bruijn, J., Ehrig, M., Feier, C., Martin-Recuerda, F., Scharffe, F., & Weiten, M. (2006). Ontology Mediation, Merging and Alignment. *Semantic Web Technologies*, John Wiley & Sons.

Ding, Y, Fensel, D., Klein, M., & Omelayenko, B. (2002). The Semantic Web: yet Another Hip. *Data and Knowledge Engineering*, 41(3), 205-227.

Ehrig, M. & Sure, Y. (2004). Ontology Mapping – an Integrated Approach. *Lecture Notes in Computer Science*, 3053, 76-91.

Gangemi, A., Guarino, N., Masolo, C., & Oltramari, A. (2003). Sweetening WordNet with DOLCE. *AI Magazine*, 24(3), 13-24.

Goh, S. (2002). Managing Effective Knowledge Transfer: an Integrative Framework and some Practice Implications. *Journal of Knowledge Management*, 6(1), 23-30.

Gruber, T. (1993). Toward Principles for the Design of Ontologies Used for Knowledge Sharing. *Formal Ontology in Conceptual Analysis and Knowledge Representation*, Kluwer Academic Representation.

Guarino, N. (1998). Formal Ontology and Information Systems. *Proceedings of the International Conference on Formal Ontology in Information Systems*, 3-17.

Leung N. K. Y. & Lau, S. K. (2006). Relieving the Overloaded Help desk: a Knowledge Management Approach. *Communications of International Information Management Association (IIMA)*, 6(2), 87-98.

Leung, N. K. Y., Lau, S. K., & Fan, J. (2007). An Ontology-based Knowledge Network to Reuse Inter-organization Knowledge. *Proceedings of the 18th Austaliasian Conference of Information Systems (ACIS)*.

Leung, N. K. Y., Lau, S. K., & Fan, J. (2008). A Design and Input-specific Classification Framework of Ontology Matching Techniques. *Proceedings of the 14th Australasian World Wide Web Conference (AusWeb)*.

Lussier, Y. & Li, J. (2004). Terminological Mapping for High Throughput Comparative Biology of Phenotypes. *Proceedings of the Pacific Symposium on Biocomputing*, 202-213.

McGuinness, D., Fikes, R., Rice, J., & Widler, S. (2000). An Environment for Merging and Testing Large ontologies. *KR2000: Principles of Knowledge Representation and Reasoning*, 483-493.

Mentzas, G., Aposolou, D., Young, R., & Abecker, A. (2001). Knowledge Networking: a Holistic Solution for Leveraging Corporate Knowledge. *Journal of Knowledge Management*, 5(1), 94-106.

Niles, I. & Pease, A. (2001). Towards a Standard Upper Ontology. *Proceedings of the International Conference on Formal Ontology in Information Systems*, 2-9.

Nonaka, I., Toyama, R., & Konno, N. (2001). SECI, Ba and Leadership: a Unified Model of Dynamic Knowledge Creation. *Managing Industrial Knowledge Creation, Transfer and Utilization*, 13-43, Sage Pub.

Noy, N. & Musen, M. (2000). PROMPT: Algorithm and Tool for Automated Ontology Merging and Alignment. *Proceedings of the 17th National Conference on Artificial Intelligence.*

Oinas-Kukkonen, H. (2005). Towards Evaluating KM through the 7C model. *Proceedings of the European Conference IT Evaluation*.

Pinto, H. & Martins, J. (2001). A Methodology for Ontology Integration. *Proceedings of the 1st International Conference on Knowledge Capture*, 131-138.

Predoiu, L., Feier, C., Scharffe, F., de Bruijn, J., Martin-Recuerda, F., Manov, D., & Ehrig, M. (2006). *State-of-the-art Survey on Ontology Merging and Aligning V2*, EU-IST, Integrated Project (IP) IST-2003-506826 SEKT: Semantically Enabled Knowledge Technologies.

Rahm, E. & Bernstein, P. (2001). A Survey of Approaches to Automatic Schema Matching. *The International Journal on VLDB*, 10(1), 334-350.

Scharffe, F., de Bruijn, J., & Foxvog, D. (2006). *Ontology Mediation Patterns Library V2*, EU-IST Integrated Project (IP) IST-2003-506826 SEKT: Semantically Enabled Knowledge Technologies.

Sheth, A. (1999). Changing Focus on Interoperability in IS: from System, Syntax, Structure to Semantics. *Interoperating Geographic Information Systems - Norwell*, 47, 5-29.

Shvaiko, P. & Euzenat, J. (2005). A Survey of Schema-based Matching Approaches. *Journal on Data Semantics*,IV, 146-171.

Smith, B. (2003). Ontology. *Blackwell Guide to the Philosophy of Computing and Information*, 155-166, Blackwell.

Studer, R., Benjamins, V., & Fensel, D. (1998). Knowledge Engineering: Principles and Methods. *Data and Knowledge Engineering*, 25, 161-197.

Wagner, S. & Buko, C. (2005). An Empirical Investigation of Knowledge-sharing in Networks. *The Journal of Supply Chain Management*, 41(4), 17-31.

This Page Intentionally left Blank